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ABSTRACT

A 1.0 mgd wastewater treatment plant, designed for biological phosphorus removal within an activated sludge system, was evaluated over a variety of operating conditions during its first year of operation. A maximum phosphorus removal rate of 0.026 pounds of phosphorus removed per pound of COD removed was measured at one particular cell residence time. High influent phosphorus concentrations, however, reduce the plant's probable performance to less than 50 percent phosphorus removal at optimum conditions. Phosphorus removal apparently occurs through a combination of metabolic and physical-chemical mechanisms. The specialized plant design has caused several severe operating problems and capital and operating expenditures are significantly greater than reported for conventional activated sludge treatment.

Key Words: wastewater treatment, activated sludge, phosphorus removal

A FULL-SCALE EVALUATION OF "LUXURY UPTAKE" FOR PHOSPHORUS REMOVAL*

By

M. C. Mulbarger, D. G. Shifflett, M. C. Murphy and D. D. Huffman**

The Greater Manassas Sanitary District (GMSD) in Prince William County, Virginia, began operation of its new 1.0 mgd wastewater treatment facility in August, 1968. The plant was designed to provide biological phosphorus removal by luxury uptake within the activated sludge systems.[1][2][3]

In a joint Federal-local investigative effort, the plant was evaluated over a wide range of operational variables. The results reported herein deal specifically with the plant's phosphorus removal capability and the influence of the specialized design upon performance of other unit processes. Capital and operating expenditures are also reported.

PLANT DESCRIPTION AND RATIONALE

Figure 1 shows schematically the basic plant flow pattern. Detailed design criteria are available elsewhere.[3]

It has been reported that the removal of phosphorus in an activated sludge system can be enhanced by promoting "luxury uptake," a biological process. The results of others indicate that the improved phosphorus removal is actually a physical-chemical phenomenon.

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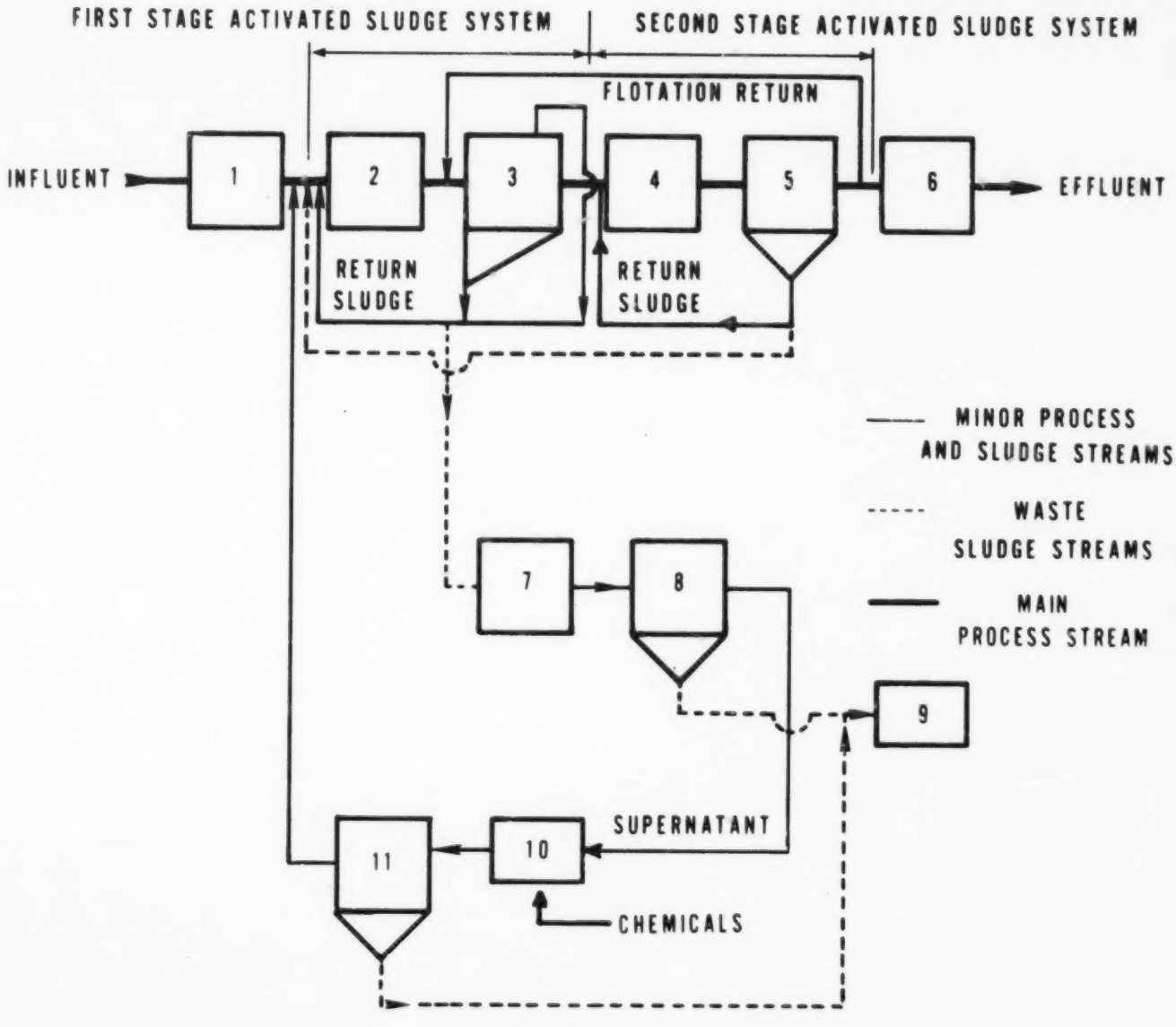

1 PRETREATMENT FACILITIES AND CONTROL BUILDING
2 FIRST STAGE AERATION TANK
3 DISSOLVED AIR FLOTATION TANK
4 SECOND STAGE AEREATION TANK
5 CLARIFIER
6 CHLORINE CONTACT TANK
7 PRIMARY ANAEROBIC DIGESTER
8 SECONDARY ANAEROBIC DIGESTER
9 SAND BEDS
10 FLASH MIXER*
11 CHEMICAL PRECIPITATION TANK*

*NOT USED

FIGURE 1. 1.0 mgd WASTEWATER-TREATMENT PLANT GREATER MANASSAS SANITARY DISTRICT

Regardless of the internal mechanism of phosphorus incorporation with the biological solids, actual phosphorus removals are dependent upon the amount of sludge wasted from the plant. Since the mass of waste activated sludge is largely influenced by the carbonaceous load applied to the biological system, maximum wastage was assured by eliminating primary clarification. Chemical treatment of the digester supernatant was provided to prevent the return of previously removed phosphorus. The dissolved air flotation unit was to provide rapid, aerobic mixed liquor solids separation in an effort to minimize anaerobically-induced phosphorus release.[4] The second-stage aerator and final clarifier were to provide additional carbon and solids removal in case the flotation effluent was not of suitable quality for direct discharge.

The original process scheme contained an anaerobic stripping tank and two-stage elutriation facility for the return sludge stream in the first-stage system. The anaerobic stripping tank was to induce phosphorus release from the return sludge and the elutriate would then be cycled to a larger chemical precipitation tank for permanent phosphorus removal. These facilities were eliminated because similar "luxury uptake" studies in the Southwest[5][6] indicated that they may not be necessary.

As stated before, phosphorus uptake in activated sludge has also been explained on the basis of physical-chemical mechanisms. Menar and Jenkins[7] report that, in hard water areas, the high aeration rates ascribed as necessary for metabolic phosphorus uptake strip out carbon dioxide, raise the pH, and cause the precipitation of a calcium phosphate complex. They indicate that the optimum condition would be an activated sludge culture in an endogenous state

(which would minimize microbial carbon dioxide formation). They recommend plug flow, diffused aeration systems.[7] Plug flow aeration patterns have also been recommended by several luxury uptake investigators[5][6] to maximize the observed phosphorus uptake at the tail end of plug flow spiral aeration systems. Contrary to the preceding, the plant's primary and secondary aerators are completely mixed, turbine systems which receive additional air through submerged sparge rings. The first- and second-stage aerators, when considered together, however, do simulate plug flow conditions and the second-stage aerator, receiving the solids in the flotation effluent, should have an activated sludge culture in an endogenous state. Other investigations have also reported that endogenous conditions can cause some organisms to accumulate and store phosphorus.[8]

PROGRAM AND PROCEDURES

Isolation Phase

The purpose of the isolation phase was to determine the optimum point of plant operation for phosphorus removal and to describe plant performance in a manner that would allow the comparison of data with other existing or planned wastewater treatment facilities. The plan was to evaluate plant performance as a function of the design alternative (with and without the secondary aerator in service) and mean cell residence time.[9][10] The data derived in this investigation should result in relationships which describe and predict the plant's phosphorus removal capability as related to influent wastewater quality, plant design, and operating conditions. Digester supernatant was not treated during these studies but its COD and phosphorus contribution to the primary aerator was considered.

Each study period encompassed four days, Monday through Thursday, and was preceded by a conditioning period greater than the approximate mean cell residence time (CRT) under investigation. Samples proportional to the flow were collected every two hours composited and analyzed daily. Sampling times were staggered through the plant to simulate the plug flow of wastewater through the plant. Aerator grab samples for analysis were collected at the beginning and end of each study period. Phosphorus and Total Kjeldahl Nitrogen (TKN) concentrations in the mixed liquor solids were determined by subtracting the soluble phosphorus and TKN levels from the total phosphorus and TKN values in the unfiltered samples. No attempt was made to differentiate between soluble and insoluble phosphorus and TKN in the digester supernatant and other sludge stream samples.

Comprehensive Phase

The purpose of the comprehensive phase was to confirm the observations derived in the isolation phase conducting a long term evaluation of the plant at the conditions for luxury phosphorus uptake. Another long-term period of operation at optimum conditions for phosphorus removal with digester supernatant treatment was scheduled but, as will be explained later, this investigation was never conducted.

Sampling procedures were the same as previously utilized except that, because of the study's long duration, no attempt was made to stagger sampling times. Aerator grab samples for nitrogen and phosphorus analysis were collected at the beginning, every three days during the study, and at its completion.

Analytical Methods

Soluble wastewater constituents are defined as those that will pass through a Whatman No. 5 filter. All phosphorus values are total phosphorus as determined after potassium persulfate addition and acid digestion.[11] Calcium and magnesium were determined by atomic absorption. Iron and aluminum were measured by Autoanalyzer techniques. Dissolved oxygen was measured by a lead-silver electrode. All other analytical measurements were performed according to Standard Methods.[12]

RESULTS AND DISCUSSION

Influent Wastewater Quality

Table 1 characterizes the influent wastewater received at the plant. It contains no industrial wastes and its high hardness content should be favorable for phosphorus removal by chemical precipitation mechanisms.[7]

Isolation Phase

Table 2 summarizes the results obtained in the isolation phase. The procedures for determining cell residence time (CRT), cell yield and endogenous decay coefficients are presented elsewhere.[9][10] Nutrient (nitrogen and phosphorus) levels in the mixed liquor volatile suspended solids were determined as defined in the analytical methods section of this paper.

Examination of Table 2 reveals the following:

(a) a dependence of sludge nutrient levels upon operation of the secondary aerator;

(b) the volatile solids percentage in the second-stage aerator is consistently lower than measured in the first-stage aerator;

TABLE 1 - INFLUENT WASTEWATER CHARACTERISTICS
(Dry Weather Conditions)

ITEM	mg/l mean ± standard deviation
COD	400 ± 70
TKN	34 ± 5
Phosphorus as P	17 ± 4
Total Solids	850 ± 70
Suspended Solids	140 ± 40
Al^{+++}	0.1 ± 0.1
Fe^{+++}	0.3 ± 0.1
Ca^{++}	70 ± 20
Mg^{++}	23 ± 4
Alkalinity as $CaCO_3$	300 ± 50
Ca^{++} and Mg^{++} Hardness as $CaCO_3$	270 ± 65
pH	7.4 ± 0.2
BOD_5/COD	0.45 ± 0.13

TABLE 2: ISOLATION PHASE: SLUDGE CHARACTERISTICS AND MISCELLANEOUS DATA

ITEM		Mean Cell Residence Time (CRT) - Days									
	First-Stage System	8.0	5.4	4.6	4.4	3.6	2.9	1.0	1.3	2.5	7.2
	Overall	11.2	5.6	8.0	5.3	4.4	4.5	1.2	1.3	2.5	7.2
Influent - mgd		0.50	0.53	0.53	0.99	0.61	0.58	0.51	0.55	1.16	0.96
Phosphorus Accounted For		75	83	107	90	127	99	129	97	80	89
First-Stage Aerator (Average Result) %	MLVSS / MLSS	64	75	72	71	74	80	81	82	78	77
	P / MLVSS	2.9	3.2	3.5	3.4	4.5	3.2	3.2	2.4	2.1	2.4
	N / MLVSS	10.8	9.7	10.5	9.8	10.9	9.3	9.2	7.9	7.4	7.1
Second-Stage Aerator (Average Result) %	MLVSS / MLSS	54	71	67	68	70	69	79	OUT		
	P / MLVSS	3.8	4.2	3.5	4.0	4.6	4.5	2.8	OF		
	N / MLVSS	11.6	10.6	11.2	10.8	12.2	13.9	10.8	SERVICE		
Measured Overall Phosphorus Removal Rate-Lb P Removed / Lb COD removed *		0.011	0.013	0.015	0.014	0.026	0.021	0.016	0.016	0.015	0.015
pH	Influent	7.4	7.8	7.8	7.8	7.5	7.5	7.5	7.5	7.3	7.4
	Final Effluent	7.6	7.8	7.8	7.6	7.7	7.6	7.5	7.6	7.4	7.4

Cell Yield Coefficient (Y) = 0.54 $\frac{\text{Lb VS Formed}}{\text{Lb COD Removed}}$

Endogenous Decay Coefficient (k_d) = 0.05 $\frac{\text{Lb VS oxidized per day}}{\text{Lb MLVSS}}$

*Measured Overall Phosphorus Removal Rate

$$= \frac{\text{(Total Phosphorus Influent + Digester Supernatant) - (Soluble Phosphorus Final Effluent)}}{\text{(Total COD Influent + Digester Supernatant) - (Soluble COD Final Effluent)}}$$

(c) nutrient to volatile solids percentages are generally higher in the second-stage than in the first-stage aerator;

(d) the volatile solids in the first-stage aerator are significantly lower at older CRTs with both aerators in service;

(e) no substantial change in the pH of the influent and effluent;

(f) a definite nutrient peaking in the sludge at a CRT of 3.6 days. This increases the plant's phosphorus removal capability as verified by the measured overall phosphorus removal rate.

Cell yield coefficients for activated sludge plants treating settled domestic wastewater are normally reported at 0.33 $\frac{Lb}{Lb}$.[9] The higher value found at this plant is attributed to a different substrate, unsettled domestic wastewater, and the basic limitation derived from using volatile solids as a measure of viable biological mass.

It should be noted that, when both aerators are in service, frequent wastage of the second-stage system's activated sludge to the first-stage system must be conducted. This is due to a solids overloading of the second-stage system from the flotation effluent's high suspended solids. The deviation from the first-stage aerator's volatile solids trend towards higher volatile solids values with younger CRTs can be partially attributed to the recycle of an excessively high second-stage system activated sludge mass during the studies with primary CRTs of 4.6, 4.4 and 3.6 days.

The mechanism (s) for phosphorus removal at this plant is not readily discernible. Referring to Table 2, observations (a) through (d) and limited analyses for calcium and magnesium removals through the plant lend support to chemical precipitation mechanisms[7] although no substantial pH change,

observation (e), was noted. Observations (a) through (c) support the mechanism of phosphorus uptake by organisms during a stress or endogenous condition,[8] although observation (d) would tend to refute this mechanism. Observation (f) supports phosphorus removal by metabolic mechanisms such as phosphorylation.[1][5][6] The apparent uptake of nitrogen in the mixed liquor volatile solids is not explained by any of the mechanisms. The authors can only conclude that phosphorus removal at this plant, at the apparent optimum primary system CRT, is occurring through a combination of metabolic and physical-chemical mechanisms which are incompletely understood.

For practical purposes, the question is - what is the magnitude of phosphorus removal possible at this plant. Figure 2 and Table 3 provide answers to this question.

Figure 2 shows the phosphorus removal capability at this plant as a function of the CRT in the first-stage system. The purpose of this figure is only to show trends. Phosphorus removals, mg/l as P, are obtained by multiplying the measured overall phosphorus removal rate from Table 2 by an assumed 360 mg/l COD removal (influent COD-soluble effluent COD). A maximum removal of 9 mg/l as P is shown. Actual phosphorus removals will be less due to effluent suspended solids. The plant's optimum phosphorus removal efficiency, for an assumed influent phosphorus concentration of 17 mg/l as P, is 53 percent; effluent suspended solids will cause the actual phosphorus removal efficiency to lie between 36 and 47 percent.

Table 3 compares phosphorus removal achieved at the GMSD's 1.0 mgd plant with what might be expected at a conventional treatment facility with and without enhanced phosphorus removal. At the GMSD's plant, failure to

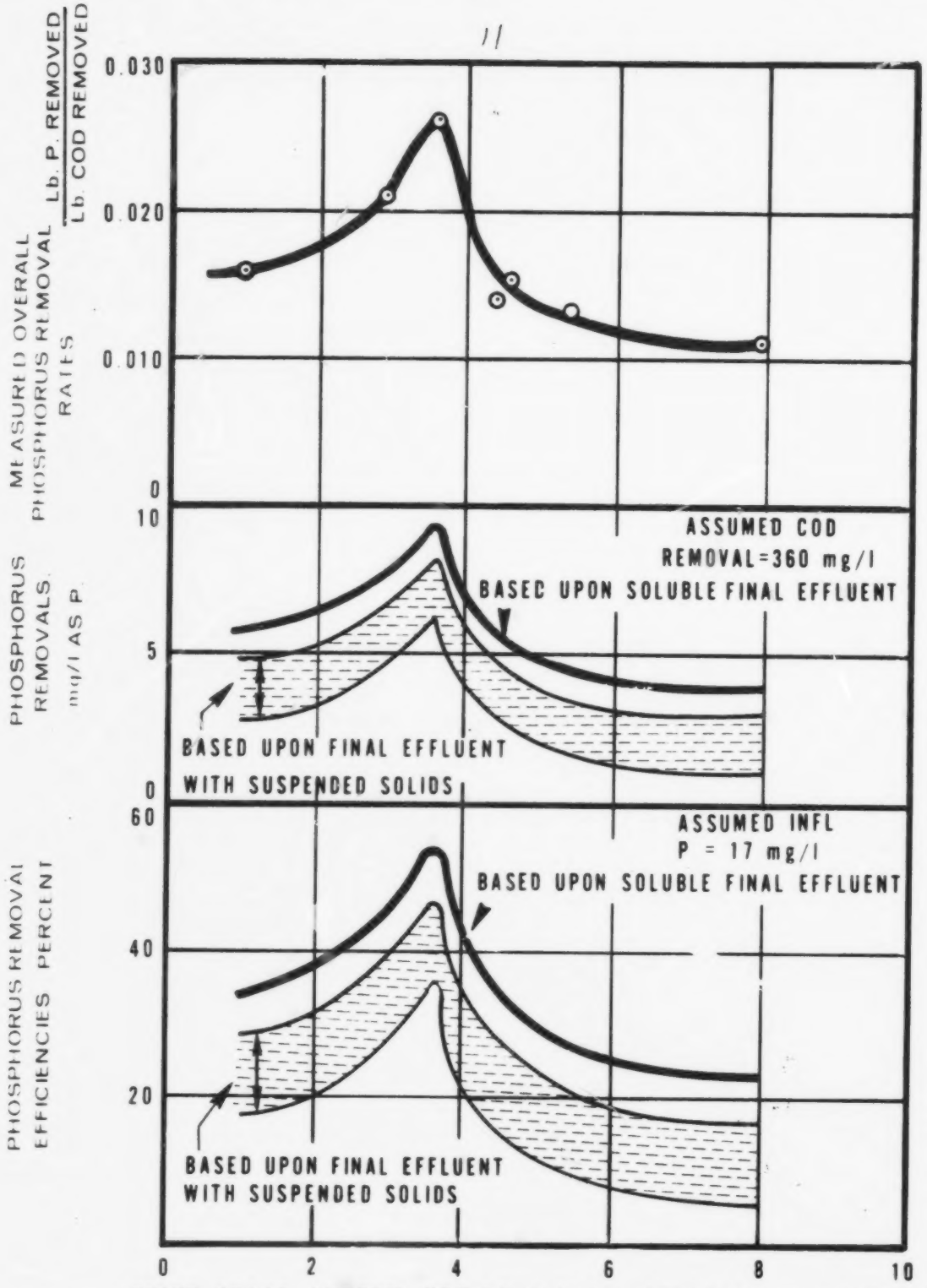

FIGURE 2. PHOSPHORUS REMOVAL CAPABILITY AT GMSD's 1.0 mgd WASTEWATER TREATMENT PLANT

TABLE 3 - COMPARISON OF PHOSPHORUS REMOVAL CAPABILITY
(Soluble Effluent Discharge)

ITEM	A	B	C=(A)(B)	D	E=(C)(D)	F		
	Assumed Sludge Production Rate $\frac{\text{Lb VSS Prod.}}{\text{Lb COD Rem.}}$	Assumed Phosphorus Content of Activated Sludge $\frac{\text{Lb P}}{\text{Lb VSS}}$	Phosphorus Removal Rate $\frac{\text{Lb P Rem.}}{\text{Lb COD Rem.}}$	Assumed COD Removal in Activated Sludge System mg/1	Phosphorus Removed mg/1	Phosphorus Removal Efficiency Based on Selected Influent Phosphorus Concentrations-Percent		
						Influent Phosphorus - mg/1		
						8.0	12.0	16.0
GMSD's 1.0 mgd Plant	0.48	0.05	0.024	360	8.6	100	72	54
Conventional plant with no enhanced Phosphorus Removal*	0.30	0.02	0.006	260	1.6	20	13	10
Conventional plant with enhanced Phosphorus Removal*	0.30	0.08	0.024	260	6.2	77	52	39

* Conventional plant is assumed to contain primary clarification and activated sludge treatment, primary clarification is assumed to remove 100 mg/1 COD.

achieve a higher phosphorus content in the activated sludge system has been more than compensated for by the elimination of primary clarification but, as will be explained later, this has also contributed to some of the severe operational problems encountered at this wastewater treatment facility. The conclusion derived from Table 3 is that phosphorus removal by metabolic and/or internal physical-chemical phenomena is limited by the biological cons constraints of the activated sludge system and controlled by the influent substrate; actual phosphorus removal efficiencies of greater than 80 percent will probably be limited to those wastewaters containing between 6 to 8 mg/l influent phosphorus and maintaining high substrate concentrations.

Comprehensive Phase

Table 4 summarizes the recommended and achieved operating conditions for the 25-day comprehensive study. The recommended conditions for luxury metabolic uptake of phosphorus were achieved in the plant in every possible instance.

Table 5 characterizes plant performance during the study. The removal of 5 mg/l of influent calcium (influent minus soluble final effluent basis) was noted but no magnesium was removed. The importance of the second-stage aerator in phosphorus removal is verified by comparing soluble flotation and final effluent analyses - a 1.5 mg/l phosphorus reduction accompanied by only a 5 mg/l change in soluble COD. An apparent solubilization of nitrogen and phosphorus is noted by the reduction in the nutrient to volatile solids ratios between the aerator mixed liquor and waste sludge solids streams in both the first- and second-stage activated sludge systems. The inability to obtain

TABLE 4 - COMPREHENSIVE PHASE: CONDITIONS FOR LUXURY UPTAKE OF PHOSPHORUS

CRITERIA	RECOMMENDED (2)(5)(6)	ACHIEVED AT GMSD's PLANT
Aerator DO - mg/l	> 2.0	5.7
Air Supply cf/gal*	3-7	Mechanical Aeration
Aerator detention time (based on Q) - hours	3-6	4.8
Organic Load Lb BOD/LB MLSS-Day	0.4 - 0.5	0.5
MLSS - mg/l	2500 - 4000	2930
Sludge Detention Time in Clafifier-hours	< 1.0	Dissolved Air Flotation unit operated for a float detention time of 0.5 Hours
Nitrification	Low	11% - Based on soluble analysis for oxidized and total kjeldahl nitrogen
Soluble Organic in Aerator	Low	COD = 56 mg/l

* cf/Gal = 0.0075 $\frac{\text{cubic meters}}{\text{liter}}$

TABLE 5 - COMPREHENSIVE STUDY: PLANT PERFORMANCE

I. MAIN FLOW STREAM - mg/l

ITEM	A Influent	B Digester Supernatant Return*	C = A + B Total To Plant	D Flotation Effluent	E Final Effluent	F = C - E Removals
pH	7.2			7.3	7.4	
COD_T	430	128	558	390	68	
Soluble COD	—	—	—	53	48	510
P	16.3	2.6	18.9	18.7	14.6	
Soluble P	—	—	—	13.8	12.3	6.6

II. SLUDGE STREAMS - PERCENT

ITEM	Aerator Mixed Liquor			Waste Sludge		
	$\frac{MLVSS}{MLSS}$	$\frac{N}{MLVSS}$	$\frac{P}{MLVSS}$	$\frac{VTS}{TS}$	$\frac{N}{VTS}$	$\frac{P}{VTS}$
First Stage System	73	9.8	2.8	75	8.7	2.4
Second Stage System	70	11.4	3.5	70	10.0	3.2

III. MISCELLANEOUS DATA

Influent = 0.83 mgd
Phosphorus accounted for = 105%
Measured sludge production rate = $\frac{0.48 \text{ LB VS Produced}}{\text{LB COD Removed}}$

First-Stage System CRT = 1.8 Days
Overall CRT = 2.3 Days
Measured phosphorus removal rate = $\frac{(C-E)_P}{(C-E)_{COD}} = \frac{6.6}{510}$

$= 0.013 \frac{\text{LB P Removed}}{\text{LB COD Removed}}$

*Calculated on an influent basis

$= \frac{\text{(mg/l in supernatant) (volume of supernatant)}}{\text{(volume of influent)}}$

a higher phosphorus concentration in the primary system's mixed liquor solids was attributed to its young CRT.

The second long-term study at a primary system CRT of 3.6 days with digester supernatant treatment was not conducted because of the onset of severe operational problems.

INFLUENCE OF PLANT DESIGN UPON OTHER UNIT PROCESS PERFORMANCE

The specialized design contained at the GMSD's 1.0 mgd plant has created a number of severe problems which make the establishment of standard operational procedures impossible. The following briefly describes the most significant problem areas.

Elimination of Primary Clarification

Although the plant's phosphorus removal capability is increased by eliminating primary clarification, significant quantities of waste activated sludge are generated which have apparently caused severe operational problems with the plant's anaerobic digesters.

Hydraulic, organic, and solids loadings are applied, unbuffered by primary sedimentation, directly to the first-stage aerator. Accumulations of grit and mud clogged the aerator's drain after four months of operation. If the flotation unit is not operated, the grease balls which form during aeration are not adequately separated and can be observed in the plant's final effluent.

Anaerobic Digestion

The means of solids handling and disposal determine the success or failure of the treatment. Figure 3 shows the chronological waste sludge volume applied to the primary digester, which is heated and mixed, and the

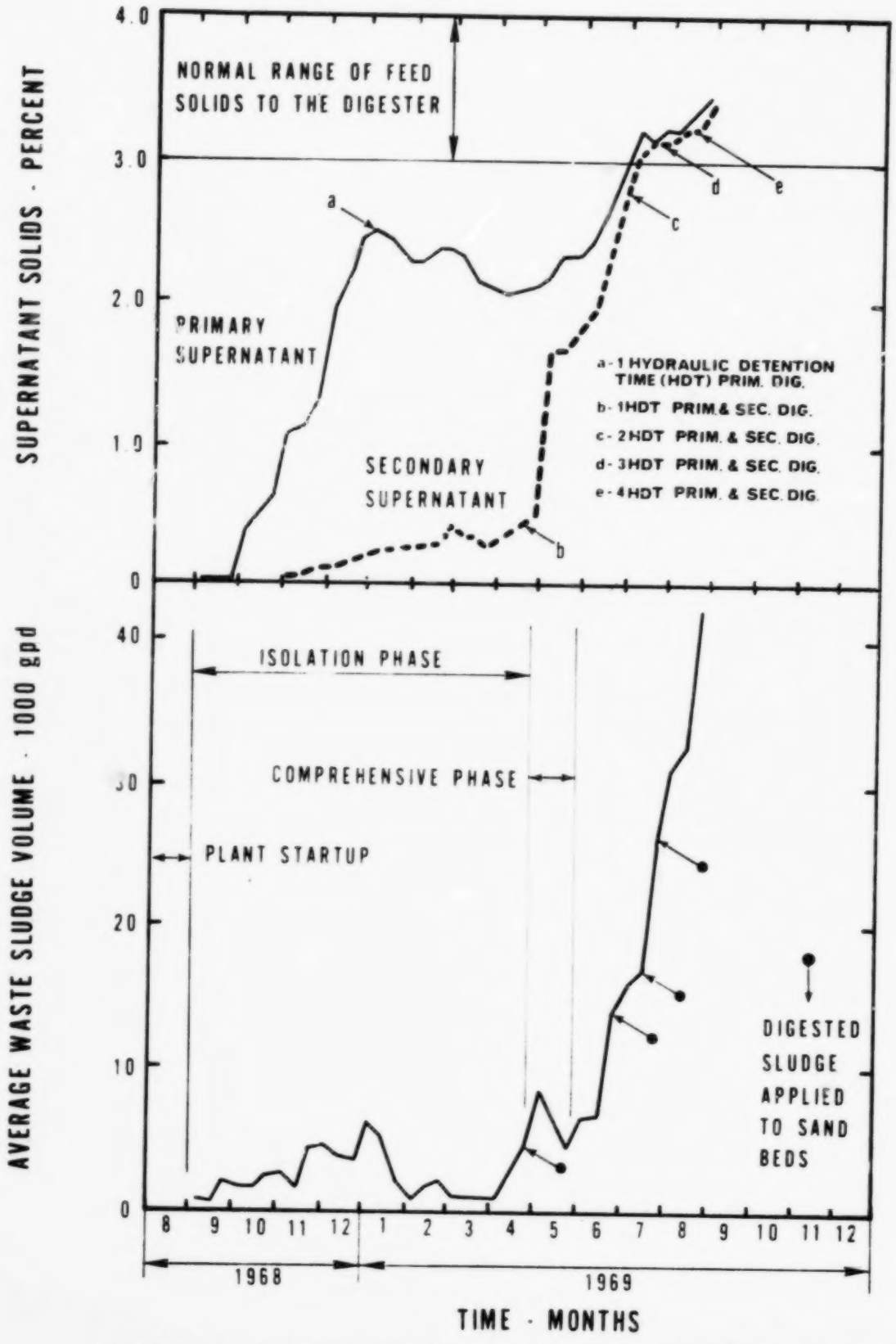

FIGURE 3. SLUDGE WASTAGE AND SUPERNATANT SOLIDS

supernatant solids from the primary and secondary digester. Failure of the anaerobic digesters and problems with the total plant started with one hydraulic detention time in the primary and secondary digester. The leveling off of the primary supernatant solids between points (a) and (b) is attributed to the recycle of sludge from the secondary digester to the primary digester, which was practiced for one hour daily.

Feeding the anaerobic digesters only waste activated sludge has led to the following observations:

(a) minimal volatile solids destruction (averaging between 10 and 20 percent),

(b) an equilibrium alkalinity and volatile acids in the secondary digester equal to 4500 mg/l and 900 mg/l as $CaCO_3$, respectively (average values during May and June),

(c) failure to achieve appreciable solids separation in the secondary digester.

Digester supernatant treatment in June by either lime or alum as the coagulant was impossible because the high chemical dosage required to satisfy the buffering alkalinity in the digester supernatant exceeded the capacity of the chemical feeding equipment. Laboratory studies conducted in August and September, when the digester supernatant's alkalinity was appreciably lower due to hydraulic failure of the digesters, indicated that lime alone and with organic polymers at a reaction pH of greater than 11.0 could not produce appreciable solids separation with gravity clarification. This was attributed to the high supernatant solids which hindered solids settling.

Solids dewatering on the drying beds is controlled by evaporation rates only since the beds seal almost instantly when the digested sludge is applied. Tank truck hauling of liquid digested sludge to nearby farmlands will be initiated in the latter part of 1969 as a temporary solution to the plant's problems.

Dissolved Air Flotation

The dissolved air flotation unit readily thickens mixed liquor solids as a function of the speed of surface skimming or float detention time. Effluent suspended solids vary as a function of the air/solids mass ratio divided by the hydraulic loading rate.(13) The flotation unit's failure to obtain adequate solids capture overloads the second-stage system with solids and this necessitates almost continuous wastage of the second-stage system's activated sludge back to the first-stage system. This not only complicates operation, it also prevents the establishment of an isolated nitrifying population in the second-stage system and thus, the discharge of a completely nitrified effluent.(14) The problems and expense of the dissolved air flotation unit make its use unjustified for mixed liquor solids separation regardless of the benefit derived in phosphorus removal.

Aeration Systems

During the isolation phase, organic loadings on the first-stage aerator varied from 0.3 to 1.8 Lb COD/Lb MLVSS-Day as different CRTs were established in the plant. Throughout these studies, high dissolved oxygen levels and low sludge volume indices (58 $\pm$ 8 ml/gm) were consistently achieved but a problem with colloidal suspended solids was noticed. This was attributed to sludge floc shearing in the first-stage aerator which produces a colloidal

solids suspension that escapes capture in the flotation unit. These colloidal solids are not reflocculated in the second-stage aerator and the result is an effluent high in suspended solids. Plant effluent quality from start-up through May is presented in Table 6 with mean removal efficiencies based upon the influent quality data reported in Table 1.

The high diffused aeration rates cited as necessary for both metabolic[6] and chemical precipitation[7] mechanisms for phosphorus removal could produce effluent suspended solids problems similar to those encountered with this plant's turbine aerators.

CAPITAL AND OPERATING EXPENDITURES

Table 7 provides a breakdown of the 1966-67 construction contract bids for both the existing and the originally-proposed plant. Approximate estimates of each unit process cost were obtained from the contract breakdown. Operating expenditures are based upon actual experience for the existing plant and estimated for the originally proposed plant.

Direct economic comparison of this type of phosphorus removal system against others would be misleading; however, a comparison can be made with the cost of conventional activated sludge treatment. Smith's[15] data at an equivalent time and amortization period show construction costs for a 1.0 mgd plant to range from $450,000 to $700,000. Total treatment costs of $0.18 per 1000 gallons are reported with a capital expenditure of $550,000. Clearly, this plant as designed, constructed, and operated is expensive both in terms of capital facilities and day to day operation.

TABLE 6 - EFFLUENT QUALITY AND MEAN REMOVAL EFFICIENCIES

Item	Mean ± Standard Deviation mg/l	Removal Efficiency %
BOD_5	28 ± 14	84
COD	77 ± 20	81
SS	36 ± 16	74

TABLE 7 - PLANT ECONOMIC ANALYSIS - 1.0 mgd BASIS

ITEM	In-Place Cost $	Unit Costs - $/1000 Gallons				
		Construction (2)	Personnel (3)	Maintenance and Utilities	Chemicals	Total
1. Plant Site & Misc. (1)	30,000	0.006				
2. Control Bldg. & Pretreatment Facilities	499,000	0.092				
3. First-Stage Aerator	129,000	0.024				
4. Flotation Unit	239,000	0.044				
5. Second-Stage Aerator	56,000	0.010				
6. Clarifier	95,000	0.017				
7. Chlorine Contact Tank	24,000	0.004				
8. Digesters	147,000	0.027				
9. Supernatant Treatment Facilities	42,000	0.008				
10. Sand Beds	35,000	0.006				
Total - Existing Plant	1,296,000	0.24	0.14	0.10	nil	0.48
11. Anaerobic Stripping & Elutriation Tanks	153,000	0.028				
Total-Originally Proposed Plant	1,439,000	0.26	0.14	0.10	0.01	0.52

(1) Does not include land costs
(2) Amortized for 25 years at 4½% interest
(3) Plant Superintendent, 5 operators, 1 Laboratory Technician

Although an additional capital expenditure of $153,000 for the anaerobic stripping and elutriation tanks may have increased the plant's phosphorus removal efficiency and many of the plant's problems can be rectified by system modification or redesign, it appears that a conventionally-designed activated sludge system receiving metal salt additions[14][16] for phosphorus removal would be economically competitive and certainly more controllable, dependable and easier to operate.

CONCLUSIONS

Enhanced phosphorus removal at optimum conditions by this plant occurs through a combination of metabolic and physical-chemical mechanisms which are incompletely understood. A maximum phosphorus removal rate equal to 0.026 pounds of phosphorus removed per pound of COD removed was found at a first-stage system cell residence time of 3.6 days. A maximum phosphorus removal of 9 mg/l as P is predicted with an assumed COD removal of 360 mg/l but effluent suspended solids reduce this removal to a lower value. High influent phosphorus concentrations reduce the plant's phosphorus removal efficiency to less than 50 percent. Operation of the plant at the published conditions for luxury uptake failed to produce the highest activated sludge phosphorus content and this was attributed to the young CRT, 1.8 days, in the first-stage system. The specialized design of the plant has created many operational problems which prevent the establishment of standard operational procedures and cause a deterioration of plant performance. The as-built plant's operating and capital expenditures are two to three times greater than those associated with conventional wastewater treatment by activated sludge.

Phosphorus removal at this plant was not adequate or subject to precise control. Internal metabolic and/or chemical precipitation mechanisms are limited by the variability of wastewater quality and performance of the activated sludge system. Although plant performance may be increased and costs decreased through system redesign, phosphorus removal by chemical additions would be more controllable and dependable. The authors are of the opinion that specialized activated sludge plant design for high level phosphorus removal should be avoided and treated as a bonus when and if it occurs.

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